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TITLE: Status of the Expansion of the Cygnus Array at Los Alamos

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STATUS OF THE EXPANSION OF THE CYGNUS ARRAY AT LOS ALAMOS

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Abstract

The CYGNUS air shower array, located in Los Alamos, New Mexico, has been operating since April, 1986. The expansion of the array from 108 to 200 counters is described along with the increase in muon detection area. The new array, to be fully operational by the end of 1989, will have three times the sensitivity to UHE sources.

Introduction The field of high-energy astrophysics has seen rapid expansion in the last several years. This is partially due to recent observations of several point sources at both VHE ($\sim$ 1 TeV) and UHE ($\sim$ 100 TeV) energies. Perhaps the most striking result was the observation of muon-rich air showers from the direction of Cygnus X-3 (M. Samorski and W. Stamm, 1983). It was in this climate of unexpected results in the UHE energy regime that the CYGNUS experiment was begun (B.L. Dingus *et. al.*, 1988).

There are several characteristics that any air-shower experiment should have to be able to search for point sources. These include good angular resolution for source identification and background supression, muon identification to reduce the hadronic background or study the muon content of showers, and low energy-threshold and large area to provide both good counting statistics and short-term burst sensitivity. As described below, the CYGNUS experiment meets all of these needs and on-going expansion will continue to increase the capabilities of the experiment.

The Past: The CYGNUS-I Array The CYGNUS air-shower array is an array of scintillation detectors deployed around the end of the LAMPF accelerator, to make use of an existing neutrino detector, at Los Alamos National Laboratory in Los Alamos, NM. It is located at 35.9°N latitude, 106.7°W longitude, and an altitude of about 2,100 m (7,000') corresponding to an atmospheric overburden of about 800 g/cm². The CYGNUS-I array currently consists of a total of 108 counters spread over an area of about 20,000 m².

Each scintillation detector has a single 2" photomultiplier tube in a light-tight fiberglass enclosure viewing a scintillator of area 0.83 m^2. The information recorded for each event includes the relative time each detector was hit (with a signal corresponding to at least about 0.1 minimum ionizing particle) as well as the relative pulse height of the signal. The detectors are regularly calibrated using single penetrating particles recorded in coincidence with a separate pair of smaller counters placed in turn directly under each detector.

Deployment of the array was accomplished in three stages; the array began taking data on April 2, 1986 with a total of about 60 counters, with 4 more added soon after, spread over about 10,000 m^2. An additional 32 counters were added in July, 1987 increasing the area covered to about 20,000 m^2. Finally, 12 counters were added in December, 1988 to fill in the remaining area to the east near the eventual location of the CYGNUS-II array. The spacing between counters ranges from about 10 m in the central part of the array to about 20 m near the edges, especially towards the east, with an average of about 14 m between counters.

A layer of lead, approximately 1 radiation-length thick, has been recently placed on all of the detectors. The lead has resulted in improvements in energy threshold and angular resolution; determination of the quantitative of improvement of energy threshold, effective area, and angular resolution is difficult, requiring many detailed studies of the data.

The array is triggered, at a rate of about 3.6 s^{-1}, by at least 20 counters in coincidence. An additional requirement of at least 8 counters being struck by at least 2 particles each, which about 70% of the events meet, is imposed before the event is recorded to tape for later reconstruction and analysis. The zenith angle distribution of recorded events, averaged over about a day of running, is peaked within 1°of the zenith and varies approximately as $\cos^8\theta_z$. The distribution is not peaked exactly at the zenith because of the irregular deployment of the detectors, mostly due to the relative height variation of about 15 m. The median number of detectors used in each fit is about 20 resulting in an average resolution of about 0.8°. The typical energy of cosmic ray triggers is about 200 TeV and the array threshold is about 50 TeV.

Muon Identification in CYGNUS-I The CYGNUS-I array is deployed around the LAMPF E225 neutrino-electron elastic scattering experiment, the first experiment to observe $\nu_e - e$ scattering (R.C. Allen *et. al.*, 1985, 1988). The E225 detector is shielded on the top by 1.8 m iron equivalent and on three of the four sides by 1.0 m iron equivalent (the fourth side, toward the beam stop, is shielded much more). This shielding corresponds to about 50 radiation lengths and about 12 nuclear-interaction lengths for the top (30 radiation lengths and 7 interaction lengths for the sides). The minimum energy required for a vertical muon to penetrate the top shield is 2.5 GeV while for a muon entering the side at a 45°zenith angle it is 2.0 GeV.

The multiwire proportional chamber detector used as an anticoincidence veto for the neutrino experiment serves as the muon detector for the CYGNUS experiment. This detector, with an efficiency greater than 99%, is a cube 6 m on a side resulting in a minimum area of 36 m^2 of muon detector; the total projected area of the detector for a typical shower is 44 m^2.

The Present: The CYGNUS-II Array The energy of events detected in a burst from Hercules X-1 in 1986 by the CYGNUS experiment was clearly different than the background distribution. There is therefore a clear indication that the spectrum of the burst events is harder than the cosmic-ray background; thus, a large air-shower array designed to concentrate on higher energies will optimize the observed signal and at the same time minimize the number of detectors required to cover a given area. This was the goal of the current expansion effort, known as CYGNUS-II , which is designed to greatly expand the area covered by the CYGNUS experiment.

The CYGNUS-II array is made up of 96 counters, nearly identical to the CYGNUS-I counters except for their area, 1.0 m^2, deployed over an area of about 60,000 m^2. The counters are arranged logically into 6 distinct "subarrays" of 16 counters each, as shown in Figure 1. The spacing between counters varies from 20 m for the two subarrays nearest CYGNUS-I to 30 m for the two furthest from CYGNUS-I ; this graded approach expands the high-energy capabilities of the CYGNUS experiment in a smooth fashion.

Instead of a single global trigger for the entire array, each subarray has its own low-level local trigger; a global trigger can be generated either by the requirement that at least some minimum multiplicity of counters in CYGNUS-II is met or by a trigger from CYGNUS-I (and vice versa). The array is controlled by the computer which operates CYGNUS-I . It is thus possible to have both arrays act as if they were simply a single, very large array without unacceptably long cable runs.

A relative comparison of the capabilities of CYGNUS-I and the combination of CYGNUS-I and CYGNUS-II can be made by calculating the integral effective area, assuming a source integral power-law spectrum with spectral index $\gamma = -1.0$, below an energy E, all normalized to the integral effective area of the original CYGNUS-I array with 64 detectors. The number of detected events from a source with such a spectrum will be 1.8 times larger for the current 108 counter array compared to the original 64 counter array. For the combination of CYGNUS-I with CYGNUS-II, approximately 2.5 times (for 10^{14} eV) to 3.8 times (for 10^{17} eV) more events will be observed compared to the original CYGNUS array. Deployment of the CYGNUS-II counters is underway and they should become entirely operational by the end of 1989.

Muon Identification in CYGNUS-II Several options for muon detection in CYGNUS-II were considered, from shielded fine-grain detectors to buried scintillator. When the option of buried scintillator was chosen, an obvious site presented itself. In nearly the exact center of the CYGNUS-II array there is an cliff at least 30 feet deep. Since the local rock is soft and easy to manipulate, a series of holes were drilled the side of the cliff and scintillator counters, taken from E225, were installed.

There are a total of 15 holes, each 36 in. in diameter and 40 feet deep, shown schematically in Figure 2. Two scintillation counters, each 30 in. wide and 10 feet long (area 2.3 m^2), will be placed in each hole; the total area for the 30 detectors is 70 m^2. The holes are covered by at least 18 feet (5.45 m) of rock, of density 1.3 g/cm^3, corresponding to a minimum overburden of 710 g/cm^2.

Conclusion The CYGNUS experiment has been operating continuously since April, 1986. The current expansion effort will increase the sensitivity of the array by about a factor of three with increased focus on higher energies. With continued effort, the CYGNUS experiment will continue to be a unique resource at the forefront of the field making observations which should help expand our understanding of the physics, both astrophysics and particle physics, operating at multi-TeV energies.

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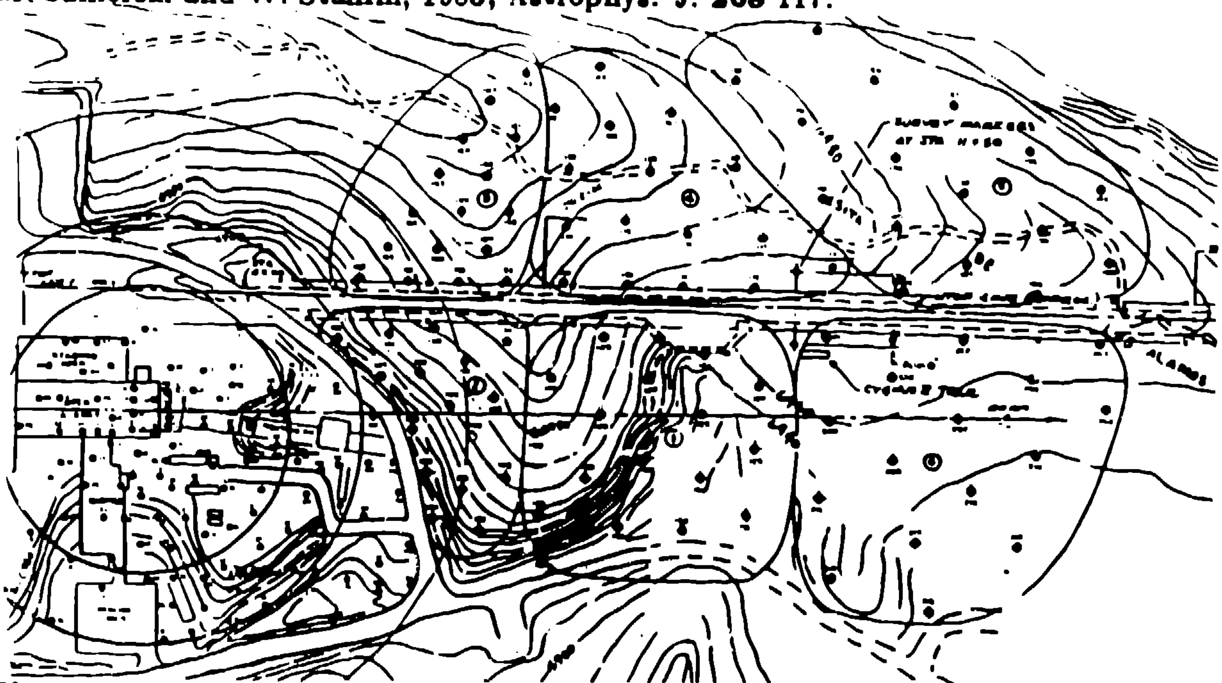

Figure 1 Deployment of the CYGNUS-II array showing the grouping into six sub-arrays.

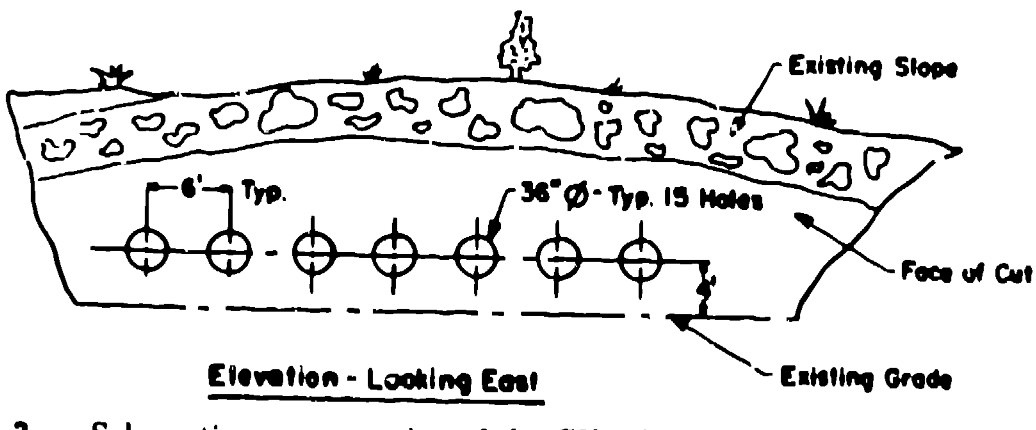

Figure 2 Schematic representation of the CYGNUS-II muon counters.

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